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Review Article

Rice blast in the Indo-Pacific Region impacting food security highlights the need for better biosecurity

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Abstract

Plant pests significantly reduce crop yield, which impacts access, availability and food utilisation. Rice is a staple crop for almost half of the world's population. Asia (including the Indo-Pacific Region, IPR) contributes 90% and consumes 86% of global rice production, but is among the most food-insecure regions in the world, with an increase of 16 million (to 113 million) moderately/severely food-insecure people in the region in the last 5 years. Outbreaks of the rice blast pathogen *Pyricularia oryzae* in the IPR could significantly affect global food security. Modelling indicates that an extreme case of 80% loss of rice crops across the IPR could increase global rice prices by 50–95%, increasing food insecurity for net exporter countries while creating price shocks in importing countries. This study used the four pillars of food security as a framework to evaluate the impact of rice blast on food availability, access, utilisation, and stability. The objective was to determine if biosecurity measures might be easily implemented to reduce the risk of the disease and increase food security in the region. Biosecurity was claimed as essential for managing rice blast across the pre-border/border/post-border continuum to reduce the risk to food security. Australia and New Zealand may be able to assist with the implementation of biosecurity measures as they are the most significant leaders in this field in the IPR. Regional agencies such as the Asia and Pacific Plant Protection Commission might assist the IPR in identifying threats through intelligence gathering and pathway modelling for pre-border activities. To be effective, the biosecurity system needs all stakeholders to work together.

Key words: Mitigation, rice blast epidemics, surveillance

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Introduction

Plants provide 80% of our food (IPPC 2020), but 40% of the global crop yield is lost to plant pests (FAO 2023a), which are "any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products" (IPPC Secretariat 2024). Plant pest outbreaks are occurring more frequently, significantly reducing crop yield while impacting market access (FAO 2009) and biodiversity (Qiao et al. 2024). These impacts are critically affecting food security. Food security occurs when "all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 1996). More than 175 million people experienced

acute food insecurity in 2024, and over 20 million were facing emergency levels of hunger. Five countries reported having more than 50% of their population in acute food insecurity (WFP and FAO 2024).

Rice grows in environments that are too wet for other crops (Hashimoto et al. 2022), thus it is a staple food in the wet tropics. Asia (including the Indo-Pacific Region, IPR, Fig. 1) contributes 90% of global rice production (FAO 2019) and consumes 86% (Bandumula 2018; Durand-Morat and Bairagi 2021). Indonesia, Vietnam, Thailand, Myanmar and the Philippines are among the top eight rice-producing countries in the world, producing 106 Mt in 2022 (Joseph et al. 2023).

Rice-blast disease outbreaks in the IPR could significantly affect global food security. Major rice blast epidemics occur regularly and can spread over large areas, with minimum annual losses of 10–30%, emphasising how crucial it is to focus on reducing these losses (Devanna et al. 2022). The rice blast pathogen *Pyricularia oryzae* [synonym: *Magnaporthe oryzae*] is a high biosecurity risk (ASEAN Secretariat 2022). For the Pacific Small Island Developing States (PSIDS), rice is not a staple crop, instead they utilise a good diversity of fruit, nut, and root crops, with staple food crops including taro, cassava, sweet potato, yam, breadfruit and coconut. The Pacific Community group provides technical resources for sustainable food systems. At the same time the Pacific Ecological Security Conference initiated collaborative networks between international and multidisciplinary participants to support on-ground activities from Strategic Action Plans (Hoffmann et al. 2024).

Biosecurity is a "strategic and integrated concept that encompasses policy and regulatory frameworks (including instruments and activities) that analyse and manage risk in food safety, public health, animal life and health, and plant life and health" (FAO 2007). The need for biosecurity has increased in response to increased food, plant and animal products trade and the associated outbreaks of transboundary diseases (Miley 2020). It encompasses a broad range of activities: policy, regulatory frameworks, procedures, and processes implemented by governments, industry, and the community to protect crops against harm from pests and diseases (McKirdy et al. 2014). Biosecurity is crucial for food security (Campbell et al. 2024), especially for protecting staple crops from plant pests.

The 1996 Food Summit investigated 25 topics related to food security (FAO 1996, 2024). The Summit's report "Food for All" recognised shortcomings in food production, including that while there was progress towards producing more food, it was not equally distributed, and 800 million people faced chronic malnutrition (FAO 1996). Agricultural production of food was exploiting and misusing vital resources; environmental impacts included deforestation, loss of biodiversity and soil and water degradation – all indicating the priority for research and investment, and the role for governments to develop polices and promote best land use practices. The FAO (1996) World Food Summit acknowledged that a reliance on high-yielding varieties of plants had increased the vulnerability to pests and diseases, and prioritised integrated pest management systems and policy adjustments to foster biodiversity. Acute food insecurity is influenced by multiple, integrated drivers that can be mutually reinforcing (FAO 1996). The four pillars of food security that were developed at the Summit apply a One Health approach to manage risks, and focus on (i) availability (e.g., primary production, imports, and stock reserves); (ii) access (e.g., physical and economic factors); (iii) utilisation (e.g., food safety, quality, and nutritional value); and (iv) overall stability (of the other pillars over time) ensuring food supply (FAO 1996, World Bank Group 2024).

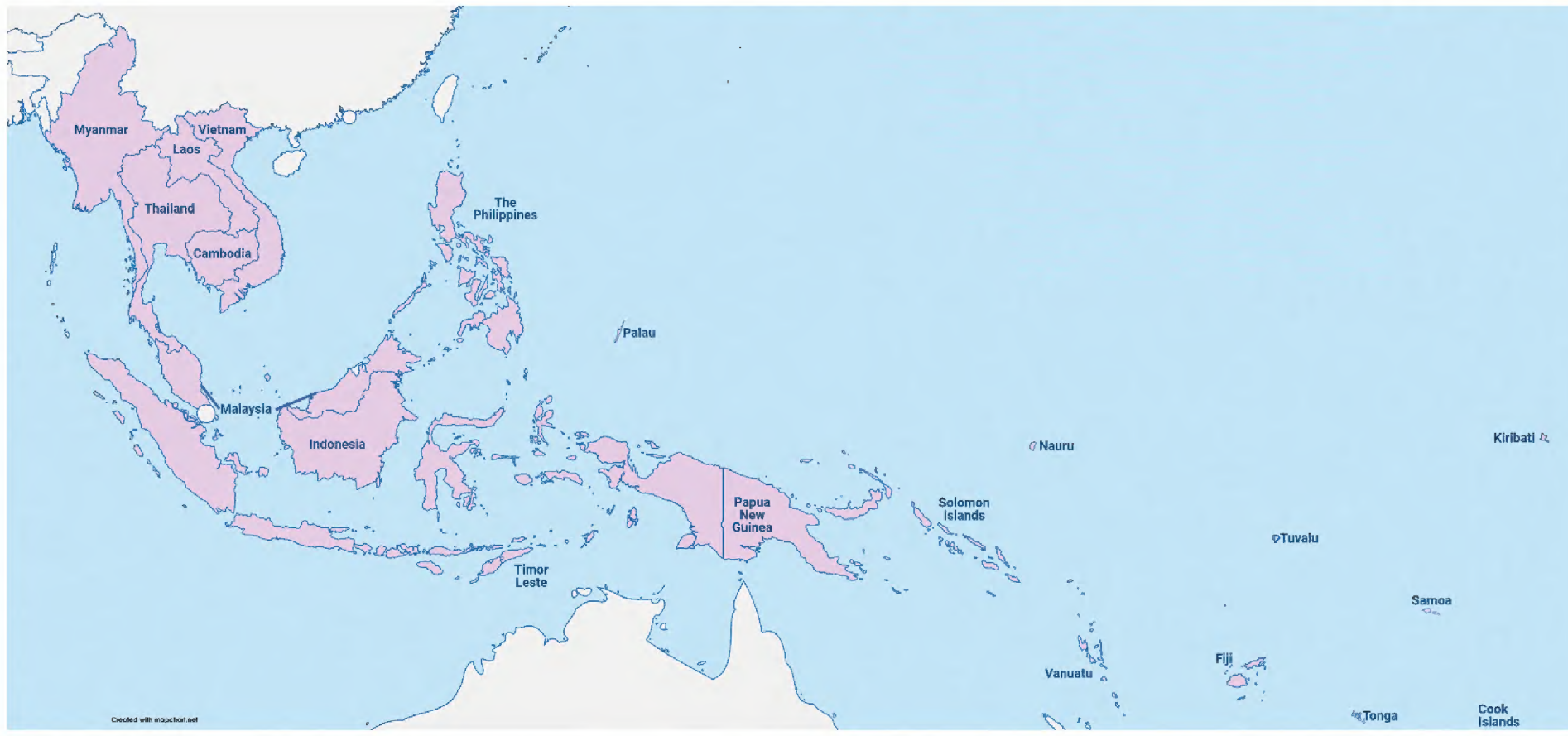

Figure 1. The countries within the scope of the project in the Indo-Pacific Region and Pacific Small Island Developing States.

Disruptions to rice production in this region directly threaten local and global security (Yuan et al. 2022), as rice is a staple crop for almost half of the global population. This study used the four pillars of food security (FAO 2024) to evaluate the impact of rice blast in the IPR on food access, availability, utilisation and stability. The objective was to determine if biosecurity measures could reduce the risk of the disease and increase food security in the region.

Methods

The study area

For this study, the following countries were considered: Indo-Pacific (9); Cambodia, Indonesia, Laos People's Democratic Republic, Malaysia, Myanmar, Thailand, the Philippines, Timor-Leste, Vietnam (defined by Department of Defence and Department of Foreign Affairs and Trade 2024) and the PSIDS (12) countries; Cook Islands, Fiji, Kiribati, Nauru, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu (Fig. 1; Smith and Houston 2023). The IPR and PSIDS comprise 52% of the world population, with most countries (72%) having a positive population growth rate (World Population Review 2024a). Five IPR countries ranked in the global top 30 most populous countries and consumed up to 270 kg of rice per capita in 2021 (World Population Review 2024b).

Data

A literature review was conducted on rice blast outbreaks and their impact on food insecurity in the IPR and PSIDS. Explicit searches using the following databases: Web of Science, CABI, Scopus, and Google Scholar and search terms including: "rice blast" or "*Pyricularia grisea*" or "*Magnaporthe oryzae*" or "*Pyricularia oryzae*" and "yield loss," and "disease" and "pathogen" and "outbreak"; "nutrition", "nutrient", "mill", and "quality". Broader terms included in searches were "biosecurity", "defence", "surveillance", and "pre-border", or "border" or

"post-border". Publications from Southeast Asia and the PSIDS were also selected, utilising snowballing (Cambridge Library 2024) to determine the occurrence of rice blast outbreaks and yield losses.

Results

State of food security in the IPR and PSIDS

The IPR countries and PSIDS are among some of the most food-insecure regions in the world, with the number of moderately/severely food-insecure people increasing from 96.5 million (2019) to 113.3 million (2023) in Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand, Vietnam, Fiji, Kiribati, Tonga and Vanuatu (Fig. 2). Food insecurity is rising in many countries, with the Philippines and Cambodia being the most affected. In Cambodia, rice is the primary source of income for 85% of rural households (Dary et al. 2017), so any impact on production has significant direct economic effects. However, high marketing and production costs are major constraints in the rice value chain, which is also negatively influenced by low yields and the lack of infrastructure and market facilities (Mataia et al. 2020). Any shocks in rice prices can result in consumers looking for cheaper imports (where production costs are lower), which can decrease motivation for local rice farming (Lim 2024). Controlling rice blast outbreaks will reduce price volatility, protecting consumers and farmers from poverty (Dawe and Timmer 2012).

There are different causes of food insecurity in each country. For example, rice farmers in the Philippines have a lower production efficiency than other countries in the region due to the price of fuel, fertiliser, and rent (Lim 2024). One of the most at-risk countries of food insecurity is Myanmar, where increasing conflict has contributed to over 10 million people (24% of the population) needing urgent action to reduce food consumption gaps and/or acute malnutrition (WFP and

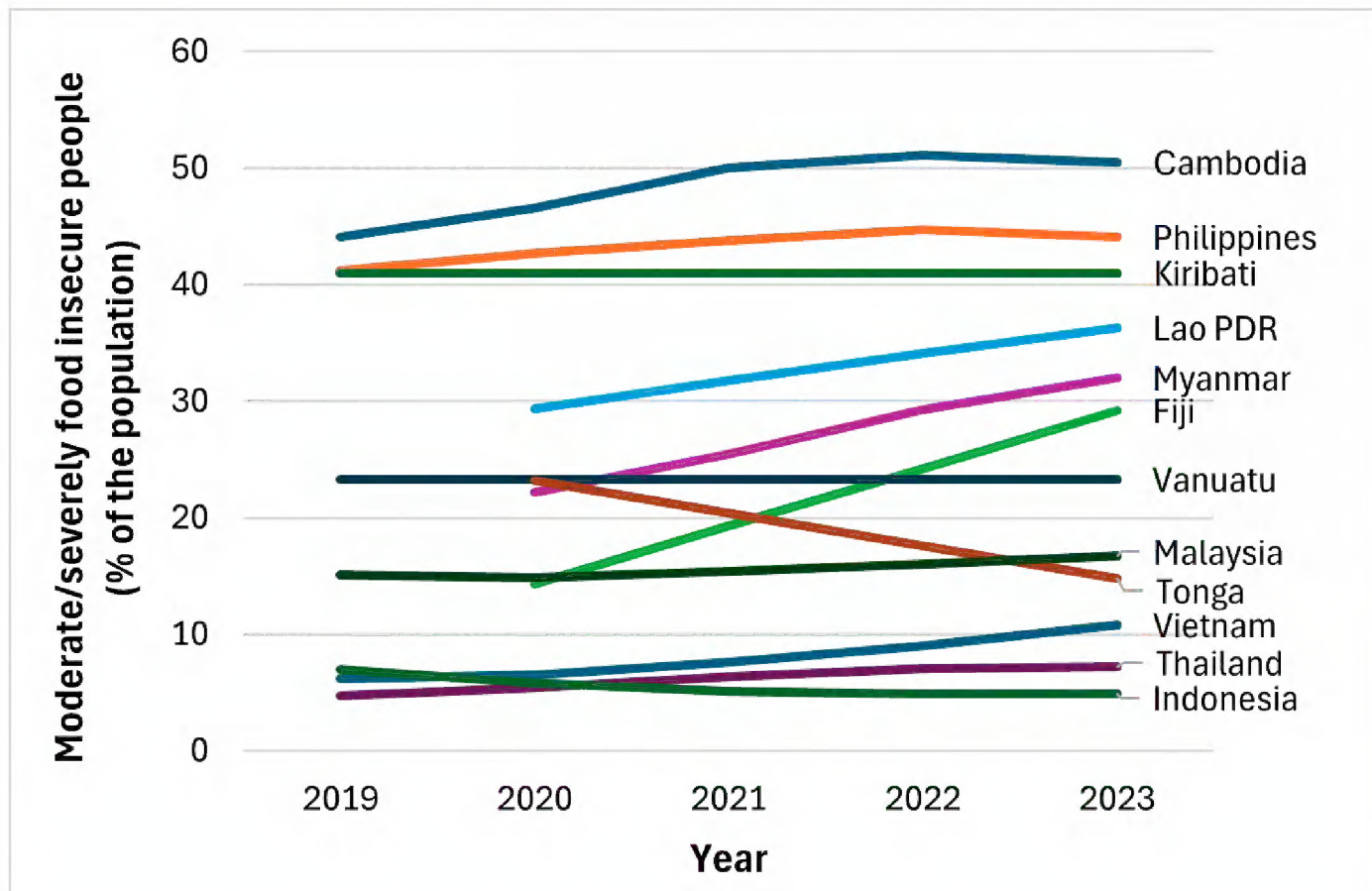

Figure 2. Food insecurity in IPR countries and PSIDS between 2019 and 2023 (data from FAOStat 2024).

FAO 2024). A further 3 million people have very high acute malnutrition and excess mortality due to a large food consumption gap and are classified as extremely vulnerable (WFP and FAO 2024). Myanmar's key drivers of food insecurity arise from conflict and economic crises, resulting in food prices almost tripling in 3 years (WFP and FAO 2024). Timor-Leste has more than 30% of the population facing acute food insecurity (FAO 2021); 47% of children under five were stunted (Ministry of Health 2020). Rice is a fundamental part of the Timorese diet, but India's increasing cost of rice exports due to their own growing population's needs puts further pressure on Timorese households and food security (WFP 2023).

The PSIDS are extremely vulnerable to climate disasters; hence, most states are not food secure; 80% rely on subsistence food production, mainly root and tree crops, fisheries and imports (Andrew et al. 2022; Georgeou et al. 2022). Notably, Fiji's percentage of moderately/severely food insecure people has doubled from 14.3 to 29.2% in the last 3 years to 2023. The region suffers from high levels of all forms of malnutrition, including childhood wasting (6 million), stunting (21 million), obesity (12 million) of children under the age of 5, micronutrient deficiencies at 46%, and 27% of anaemic women of reproductive age (UNICEF 2021; WFP 2023). Thus, multiple challenges threaten food (and nutritional) security, even before plant pests are present.

Within the PSIDS, it is estimated that a quarter of the 12.5 million people experience moderate to severe food insecurity due to access to resources or poverty (FAO 2021). The prevalence of undernutrition in PSIDS was 20.9% in 2022, which is more than double the world average (FAO 2023b). The region's heavy dependence on imported foods leaves it vulnerable to price shocks and supply shortages (FAO 2021). Of all Pacific Islanders, approximately 80% supplement their diets with produce from their village food gardens (Georgeou et al. 2022). Having the leading role in growing and selling produce, women are essential in addressing Pacific food supply and security issues (Balakrishnan 2005, Georgeou et al. 2022). As rice continues to become a preferred component of Pacific diets due to its ease of preparation and long shelf life compared to root crops, there is an increased reliance on importing this staple from Southeast Asia (FAO 2021), but increasing imports indicate diminishing food security (Georgeou et al. 2022). Utilising imported food, such as rice, can expose countries to price volatility and external shocks that disrupt the global supply chain (FAO 2021). Imported foods are not evenly accessible to the whole population, and there is inequality in dietary energy distribution, with women, children and the lower rural socio-economic groups at the greatest risk (FAO 2021).

Epidemiology and distribution of rice blast (*Pyricularia oryzae*)

Rice blast has been infecting rice crops for almost 400 years (Couch et al. 2005) and has spread worldwide in rice-growing regions (Fig. 3). In some countries, it is considered an endemic pathogen including Southeast Asia (Gladieux et al. 2018), while others have occasional outbreaks; regardless, this pathogen has the potential to cause significant yield losses (Devanna et al. 2022). The disease spreads quickly via spores, with thousands of spores produced per infected plant within a week (NSW DPI 2024), dispersed on seeds, tools, machinery, clothing, wind, and water (Molinari and Talbot 2022). Rice blast occurs in temperate and tropical agricultural environments (Nalley et al. 2016). Disease is more prevalent in areas with

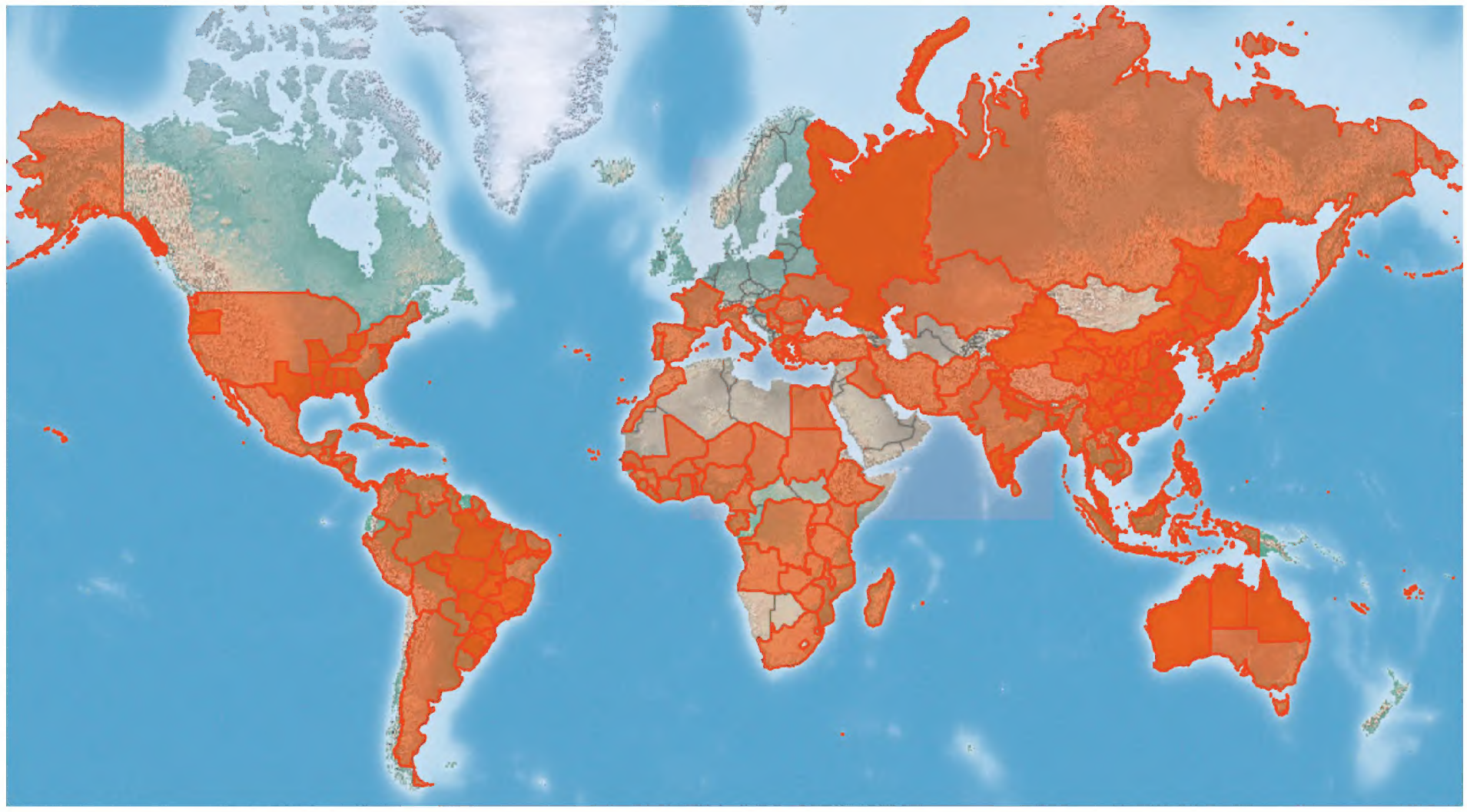

Figure 3. Distribution of rice blast (*Pyricularia oryzae*). Dark red areas are regions with regular outbreaks (considered endemic), and orange areas are where it has been reported. Map based on data that CABI believe are the most reliable Plant Wise Plus Knowledge Bank records. (16 November 2021; https://plantwiseplusknowledgebank.org/doi/10.1079/PWKB.Species.46103).

high humidity and temperatures or other stressors such as drought and excessive nitrogen use (Piotti et al. 2005). Rice grown in lowland areas has greater blast development due to optimal temperatures, high relative humidity and more spores released than in upland paddies (Phi 2023).

The pathogen can kill infected seedlings or plants up to the tillering stage (IRRI 2024). Rice blast symptoms are seen in leaves (leaf blast), the collar (collar blast), in culm, culm nodes and panicle neck nodes (neck blast), or panicles (panicle blast) (Nalley et al. 2016). During the late growth stage, grain yield is directly reduced by severe leaf blast infections, damaging the leaf area and negatively affecting the grain fill (IRRI 2024). Rice blast is adaptable to its environment, as demonstrated by genetically diverse *P. oryzae* isolates analysed from different regions (Zhong et al. 2018). This high variability allows the pathogen to constantly evolve (Nizolli et al. 2021). Thus, most rice varieties lose their resistance after a few years (IRRI 2024, Jiang et al. 2020); hence, breeding research is ongoing. The pathogen can survive in infected rice residues left in the field for up to 18 months, thus creating a fresh outbreak for the next crop (Raveloson et al. 2017). With most rice grown in temperate and tropical areas and the pathogen's survival on residues and seed, the spread of new variants threatens crops in most rice-growing areas. Identifying sources of *P. oryzae* inoculum and distribution pathways is essential to minimise rice blast outbreaks.

Rice blast has been affecting Australian rice yields since 2011. Its range is expanding in the northern parts of the country, where it is present in wild rice (*O. australiensis*), which is endemic to large areas and allows the formation of large inoculum reservoirs, leading to outbreaks (You et al. 2012, Pak et al. 2021). However, commercial rice-growing areas in southern NSW remain disease-free (Pak et al. 2021) as these crops are outside the natural range of Australian native

rice and *P. oryzae* (Khemmuk et al. 2016). With some rice-growing areas adjacent to wheat crops, and rice crops sometimes being rotated with wheat crops, there is potential for pathogens to jump species (Pak et al. 2021); hence, stringent hygiene measures and vigilant biosecurity/surveillance are utilised to reduce the spread of *P. oryzae* strains pathogenic to rice into the southern regions. By closely monitoring the distribution and inoculum loads of the pathogen, it may be possible to reduce the consequences of favourable environmental conditions for future crop outbreaks.

Understanding rice blast in the IPR using the food security pillars

Availability

Food availability hinges on the supply of food, where it exists in adequate amounts and appropriate quality and is derived from agricultural production, domestic stocks (in storage), food imports and exports, humanitarian food aid, or a combination of these sources (Bahn et al. 2021). Most rice is consumed in the same country where it is grown (Savary 2024). Availability is directly affected by pests and disease outbreaks, which reduce the growth and yield of the crop.

Primary production – impact of rice blast on yield

Data on yield loss due to rice blast was limited to five countries (Table 1). Indonesia's production has been declining in some areas due to heavy losses to rice blast (Suganda et al. 2016, Suriani et al. 2015; Table 1). Indonesia's highest rice-producing provinces–East Java, West Java, and Central Java–are prone to rice blast outbreaks (Octania 2021; Fig. 4). Severe rice blast outbreaks were recorded in Java in 2010 and 2011 (Nasruddin and Amin 2013), and in 2021 in three regencies of West Java rice blast incidence ranged from 53 to 100% (Khairani et al. 2024). In

Table 1. Records of rice yield losses due to rice blast (*Pyricularia* oryzae) across the Indo-Pacific Region.

Country	Year/s	Yield loss (%)	Source
Indonesia	2004	70	Sobrizal and Anggiani 2007
	2012	50–90	Nugroho et al. 2013 as cited in Suriani et al. 2015
	2014	61	Suganda et al. 2016
Philippines	1963	50–85	IRRI 2010
	1969–1970	70–85	IRRI 2010
	Annually	50–85	Leung 2013
	Annually	11–30	Malicdem and Fernandez 2015
Thailand	1982	60	IRRI 2010
	2013	55–75	Kirtphaiboon et al. 2021
	2015	20–70	Kirtphaiboon et al. 2021
	2017	20–50	Kirtphaiboon et al. 2021
	Annually	Up to 50	Sriboonjit and Viboonpong 2000 as cited in Wangsawangv et al. 2018
Vietnam	2006	38–65	Huu Hai et al. 2007
Malaysia	2005	50–70	Zakaria and Misman 2018, Latiffah and Norsuha 2018
	2015	50	Nurul Nahar et al. 2020

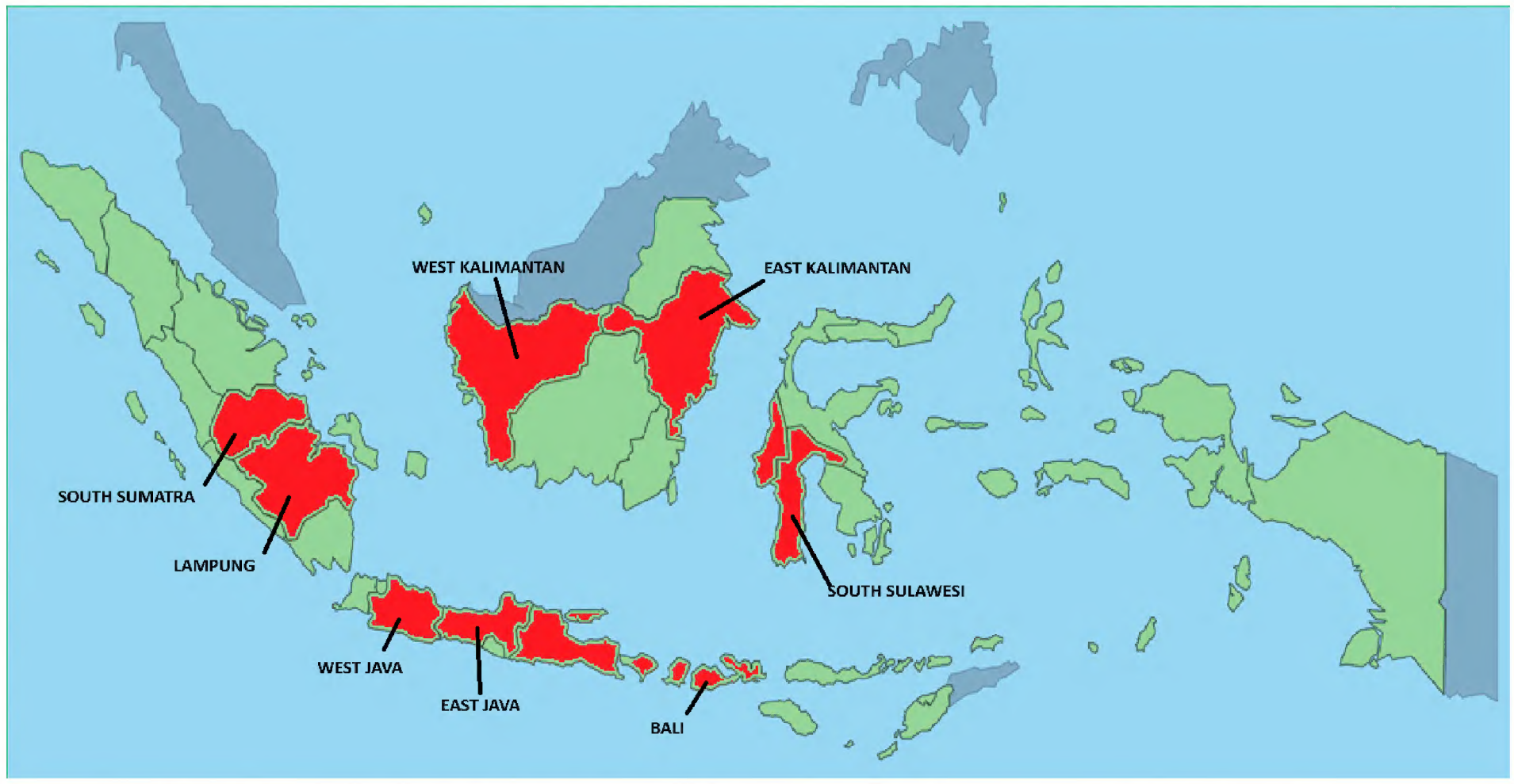

Figure 4. Indonesian provinces where rice blast is endemic (Kadeawi et al. 2021; Kuswinanti et al. 2023; Sanuriza et al. 2024). Created with mapchart.net.

one of these regencies, the rice blast incidence was 100% with a severity of 67%, and even during drought, this area suffers a disease severity of 36%, indicating that the disease is endemic here.

Rice blast outbreaks in Thailand were compared during the El Niño induced drought in 2015 to La Niña years (2013, 2014, and 2016; Kirtphaiboon et al. 2021). In 2013, there were outbreaks in three provinces with 40 to 75% disease severity (Kirtphaiboon et al. 2021). In 2015, Nakhon Nayok experienced 20 to 70% disease severity, which was lower than in the other provinces. In 2016, the disease severity in all provinces was up to 28% but increased to up to 50% in Nakhon Nayok in 2017 (Kirtphaiboon et al. 2021), indicating higher disease prevalence during La Niña years.

In 2015, it was estimated that Malaysia had ~300,000 rice farmers dependent on their crops for household income (Nurul Nahar et al. 2020), with up to 50% loss to rice blast (Table 1); this entailed hardship for these families and farm workers.

Very little data is available on rice blast losses in Vietnam (Table 1). In Vietnam, rice blast is endemic in the Red River Delta and the Mekong Delta (70% of Vietnam's total rice area), parts of the Central Region, and the northern mountainous provinces (Le et al. 2023). Rice blast generally thrives under humid conditions at 27–32 °C. Vietnam's tropical and humid environment is ideal for spreading the rice blast fungus (Phi 2023), reducing access to rice by 40 million people who work in agricultural cultivation (Liu et al. 2020). Over 50,000 ha have been infected with rice blast disease (Plant Protection Department of MARD 2020). Popular rice varieties continue to suffer significant losses; for example, Koshihikari, valued for high palatability, is highly susceptible to blast, and severe epidemics occur (Ishikawa et al. 2022). Reduced growth and production due to rice blast in Vietnam creates a need for increased reliance on rice imports (Le et al. 2023), meaning that the rural and remote communities have less rice available to trade. To aid these farmers, more modern infrastructure, education on good agricultural practices and

the most efficient use of agrochemicals are needed (Nodin et al. 2023). This includes implementing suitable farm biosecurity plans.

Major rice production failures were experienced in IPR countries because of the El Niño events, resulting in temperatures conducive to rice blast disease outbreaks (Godfray et al. 2016, Nurhasan et al. 2022; Table 1). Godfray et al. (2016) point out a slight chance that a particularly virulent strain might arise and substantially reduce yields in many countries; this is feasible as the pathogen has high variability, is airborne and transferred by spores and on seed (Jiang et al. 2020, Nizolli et al. 2021; IRRI 2024). A significant source of rice blast inoculum is rice seed (Guerber and TeBeest 2006) potentially exacerbated by informal seed sharing within countries and across borders. These and other losses possibly caused many people to suffer greater food insecurity in importing countries during the El Niño events.

The Association of Southeastern Asian Nations (ASEAN) estimated that there would be a surplus of milled rice in the 2024 season for IPR countries (ASEAN Food Security Information System 2023). The consistent rice production levels were attributed to increased planted and harvested areas (ASEAN Food Security Information System 2023). The ratio of production to domestic utilisation (an indicator of self-sufficiency) remained above 100%, indicating that rice production in the ASEAN was aggregately sufficient for domestic supply. However, some countries import rice for domestic consumption, e.g., the Philippines, Malaysia, and Indonesia (Patunru and Ilman 2019). Rice imports are likely to increase when a rice blast problem impacts production, but more data needs to be collected.

Stock reserves

Rice production in Southeast Asia has exceeded the region's demand over the last 5 years, providing stock reserves. However, rice blast outbreaks can upset these reserves and their subsequent trade. Current rice stock levels must be monitored to ensure that shortfalls might be accessed from other reserves.

In 2023, ASEAN members agreed to prioritise regional rice yield surpluses for Southeast Asian countries (Donnelly 2024). Indonesia produces most of the rice needed for its consumption, with some importation required (Octania 2021). The agreements include Indonesia stockpiling rice from Cambodia and Myanmar in preparation for El Niño seasonal shortages exacerbated by increased rice blast epidemics. These agreements demonstrate planning towards food security in the region. In another encouraging example of Southeast Asian solidarity and a move towards regional self-sufficiency, Vietnam, one of the region's largest rice exporters (Ishikawa-Ishiwata and Furuya 2022), and the Philippines (the second largest rice importer; Teng 2022) will prepare a 5-year pact that safeguards food security among their nations (Donnelly 2024; Guild 2024). This prioritisation of the IPR rice trade between regional partners will support the exporter's domestic economy and provide food security for importers and consumers.

When serious rice blast epidemics create production losses/shocks, countries may impose export restrictions, price subsidies, and import facilitation to protect their citizens and ensure self-sufficiency. If exporting countries have low rice stocks caused by disease, then consideration of rice for domestic supply and the domestic market prices may result in export restrictions being put in place. When this happens, other countries often follow suit (Laborde and Mamun 2023). Depending on the length of an export ban, these measures can cause price shocks for import-

ing countries (including PSIDS) who face higher global prices, while nationally, the increased local supply might lower prices (Valera et al. 2024). Changes to current importing/exporting strategies need to be considered to create a supportive, unified region. Creating a biosecurity community of practice may also reduce the need to impose such restrictions.

Trade (import/export)

The IPR depends heavily upon the movement of rice between its member countries (Brewer et al. 2023), so any significant losses due to rice blast will affect trade and be financially detrimental to the exporter and the importing countries reliant on rice as a staple. Thailand may remain food secure as its domestic market consumes about 50% of its rice production, with the remainder exported (Napasintuwong 2019), although they do import some preferred varieties that they do not grow, such as Basmati from India and Pakistan (WITS 2025). However, as Vietnam is one of the largest rice exporters, there are serious implications for the region when there are rice blast outbreaks, and effective planning by policymakers and stakeholders needs immediate attention for crop production (Jiang et al. 2019) and storage. The countries currently importing rice from Vietnam may need to consider a diversification strategy to avoid price shocks.

In 2021, 27% of global rice exports were from IPR countries (ASEAN Secretariat 2022). The impact of COVID-19 on food security highlighted the vulnerability of net food- importing countries (Thow et al. 2022); rice blast could create further vulnerability. An advantage can be gained via intra-regional trade agreements by reducing trade barriers (both tariff and non-tariff) (Krapohl and Fink 2013), improving economic stability for developing countries (Krapohl 2020) by saving on translocation costs, reducing food miles and creating more robust, supportive relationships with near neighbours.

The countries forming the core positions of the IPR rice trade network are Thailand and Vietnam (Chen and Zhao 2023). Export restrictions are often driven by production shocks (caused by climate, pests and diseases). Low production may result in low rice reserves in exporting countries, creating concerns about short-term availability and unstable domestic market prices, and can trigger governments to restrict exports (Laborde and Mamun 2023). When a major exporter imposes export bans, a cascading effect can significantly impact poverty and food security (Laborde and Mamun 2023). No data was found regarding the rice trade network within or between the PSIDS.

Access: Rice blast's impact on physical and economic access

The socio-economic consequences of rice blast outbreaks include the effect on rice's physical and economic access.

Economic access

When blast causes rice shortages, the price rises, making it too expensive for lower socio-economic households to buy their staple food, leading to hunger, malnutrition, and political instability (Timmer et al. 2010). An individual country's economic policies can have a regional ripple effect (Freedman 2013). For example, in 2023,

the Philippine government implemented a one-month price ceiling on rice, with Myanmar and Malaysia following suit (Donnelly 2024). The least developed countries (e.g., those in South Asia and Southeast Asia; Laborde and Mamun 2023) are the most negatively affected by export restrictions, creating price shocks or restricting access to nutritious food, causing large impacts on poverty and food security.

The economic risk that rice blast might pose to East and Southeast Asian people was investigated using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) (Godfray et al. 2016). They examined the effect of an 80% yield loss over a short term, with several scenarios investigated in individual countries and simultaneously in several countries. The assumptions and limitations of the models were critiqued (e.g., stock reserves were not included, which would influence the outcomes of price volatility/shocks), but the main finding points to a cautionary warning; that a Southeast Asian outbreak of rice blast may increase the global rice price by 50–95%, resulting in all countries affected becoming net importers. If the worldwide commodity trade remains unrestricted and responds promptly, food security will have many short-term effects. Decisions made by relevant policymakers will influence outcomes. The model showed that a small effect on calorie consumption would occur in relatively wealthy countries (e.g., Malaysia and Thailand). For less wealthy countries where calorie consumption is much lower (e.g., Indonesia, Philippines, Laos, Myanmar and Vietnam), the demographic details of the individuals will influence the level of increase in hunger (e.g., access to food is generally more difficult for rural and remote areas due to lack of infrastructure). There will be multiple flow-on effects when countries that are net exporters (e.g., Myanmar, Thailand and Vietnam) become net importers, and pre-existing importers are dramatically impacted.

Food prices at global and domestic levels significantly influence export restrictions and vice versa (Giordani et al. 2012). For example, India's restrictions on rice exports have led to significant price volatility across the IPR. Food price volatility is often blamed for food riots, however, research indicates that rising food price levels are the cause and that variation via food price volatility may decrease food rioting (Bellemare 2015). Price volatility can be caused by changes in the supply and demand of crops, disease outbreaks (or adverse weather, which can directly increase disease), and reduced production. Price volatility has the biggest impact on lower socio-economic households in low-income countries, who must allocate 75% of their income to food (Bellemare 2015). Price increases can disproportionately affect low-income households, who spend a larger share of their income on food. Given South Asia's fragile food security, restrictions on rice exports are likely to worsen the situation further, and these least developed countries are the most affected by export restrictions (Sharma and Karthikeyan 2024). Due to most South Asian countries' heavy reliance on Indian rice imports, supply disruptions and price hikes could increase food insecurity in the region.

Physical access

In rural Asia, 50% of rice growers are smallholder farmers, where 80% of family farms are ≤2 ha but produce more than 80% of the food for the area (FAO 2015b). People in these areas are the most affected by rice blast disease, where loss is high, there is a dramatic impact on populations fed mainly on rice. Unlike those who live in urban areas where the markets and supermarkets can offer alternate food

during times of rice shortage, rural area populations generally have limited access to food and financial resources, exposing them to food insecurity (FAO 2015a). Trade policies, volatile market prices, and a general lack of infrastructure can exacerbate the challenges faced by smallholder farmers. In Vietnam, for example, crop income equates to 55% of the household income, with livestock and wages/business income contributing similar amounts (Benfica et al. 2024). When crops are infected, food sources and income are reduced, and the labour cost and the failed crop are lost. Access to food for those smallholder farmers becomes difficult.

These smallholder farmers face numerous socio-economic constraints that limit their access to resources, technology, and markets. Resource-poor farmers constantly have a high risk of losing their investments, and rice blast outbreaks resulting in >50% of crop loss are financially crippling for these farmers who are hovering above the poverty line. There are local ramifications when remote smallholder farmers cannot produce a crop. For example, those reliant on a wage or a direct source of food suffer – labourers are unable to provide for their families due to a lack of income – they may generally spend 50% of their total income on rice alone (Ziegler and Barclay 2008). In the households, the women and children are the first to go without sufficient food (due to income shock and direct accessibility to rice). There is greater stunting and wasting in children from lower socio-economic families, especially from rural areas (FAO, UNICEF, WFP and WHO 2021). Without income and funds for the next crop, money is diverted from other activities such as education and health care (World Bank Group 2022). The fragility of this system, which supplies so much of each country's rice, is alarming.

The 2023 global shortage of 8 Mt of rice resulted in high prices, reducing consumers' purchasing power (Donnelly 2024). Economically vulnerable communities faced deeper food insecurity and financial hardship, causing more regional public health concerns. The prevalence of severe food insecurity in Southeast Asia continues to rise annually, making the rice shortage particularly damaging (Donnelly 2024). Unfortunately, no data was available for the PSIDS countries.

Utilisation: Exploring the effects of rice blast on rice nutritional value

Utilisation refers to the translation of the available food into nutritional security for the household and individuals, i.e., to safely prepare the food (including clean water and sanitation), the nutritive quality of the food, and proper balance of macro- (calories) and micro-nutrients (vitamins and minerals) (Bahn et al. 2021).

Rice provides up to 76% of the calorific intake in the Indo-Pacific Region (Fitzgerald et al. 2009) and a significant amount of vitamins and minerals that meet the daily nutrient requirements of those dependent on rice as an important source of energy (Juliano 1993). Rice is 80–85% starch, 6–8% protein, 3% fats, and 0.5–3% fibre (Butardo and Sreenivasulu 2016). Whole rice grains have protein, carbohydrates, fibres, vitamins (including thiamine, riboflavin and niacin), minerals such as iron and zinc, and bioactive compounds such as polyphenols, phytochemicals, and antioxidants (Carcea 2021, Kowsalya et al. 2022, Santoso et al. 2023). Rice's chemical composition and nutritional value depend on various environmental conditions during production/transport/storage, storage duration, and milling (Rohman et al. 2014, Kowsalya et al. 2022).

Rice blast changes rice's physico-chemical properties and affects its commercial value but not its nutritional quality. Infected rice is not directly harmful to humans

if consumed (TeBeest et al. 2007). However, Zakari et al. (2024) found significant differences between non-infected rice, which contained more protein (1.2%) and fat (7.7%), while there was less carbohydrate (72%) and fibre (13.6%), compared to infected rice (0.88, 6.1, 75.1%, and 16.3%, respectively). Interestingly, fungal-infected grain had increased fibre compared to the non-infested rice. Sheath-blight-infected rice can have unfilled, chalky, and cracked kernels. Infected rice may cause high variability in its physical properties, reducing its milling quality (Candole et al. 2000). This suggests that infested rice is safe to consume if no other supplies are available. Still, more work should be conducted to determine sensory values and safety. No infected grain should be planted due to the high risk of disease spread.

Stability: maximising the stability of availability, access and utilisation

"To be food secure, a population, household or individual must have access to adequate food at all times. They should not risk losing access to food as a consequence of sudden shocks (e.g., reduced yield due to disease, an economic change due to local disease or imports affected by disease) or cyclical events (e.g., seasonal food insecurity)" (FAO 2006). Shocks create short-term and temporary (transitory) or long-term and persistent (chronic) food security, while seasonal food security is usually predictable and follows a sequence of known events (FAO, IFAD, UNICEF, WFP and WHO 2022). While acute insecurity often occurs from interactions of multiple factors (Alkire 2003, Adger et al. 2014), the rice blast outbreaks resulting in a high percentage of yield loss significantly contribute to food insecurity in many IPR countries, particularly in remote, rural populations. To minimise the production shock on diets and hunger in the affected region, a rapid response from the global commodity trade system will be required, as some of the most severe effects of this simulated epidemic may be experienced in countries reliant on rice imports (Godfray et al. 2016).

Options to improve stability with new cultivars and improved disease diagnostics

Rice blast outbreaks cause availability and access to become unstable, resulting in food insecurity. Although short-term, price volatility significantly affects the poorest households, usually in regional areas with limited access to food supplies. In importing countries, price shocks can last extended periods due to export bans, affecting dietary choices and impacting those in the lowest socio-economic groups and those with limited access to interim alternative food supplies.

Rice breeding for resistance is a sustainable strategy for combating rice blast. However, the pathogen's high variability (Jiang et al. 2020, Nizolli et al. 2021, IRRI 2024) means that breeding research must be ongoing. Farmers in developing countries need help managing plant diseases due to a limited understanding of disease processes. They generally lack access to information and technology, and their disease management is often ineffective (Nelson et al. 2001). These farmers are in a never-ending battle against an evolving and spreading disease.

In Vietnam, many rice cultivars are used (Le et al. 2023), resulting in a highly diverse rice blast population in the variable geographic growing regions, meaning that control methods need to be tailored to each combination. However, the lack of understanding of the area's pathogen population limits the use of resistant cul-

tivars (Phi 2023). Breeding resistant rice varieties requires genetic knowledge of *P. oryzae*, which requires more sampling and molecular studies (Phi 2023), highlighting the urgent need for diagnostic laboratories. Then the farmers can be presented with access to current resistant varieties to enable a reduction in the need to use fungicides in the field.

Thailand's largest rural sector (in the Northeast) has the country's poorest land quality (Ahmed et al. 2023). Most of the smallholder farmers here have elementary/primary school levels of education, and policymakers are looking to redesign agricultural plans so that agriculture can focus on reducing rural poverty (Ahmed et al. 2023) and thus increase food security in this region. New technologies are utilised to improve rice production. For example, harvest dates are determined using remote sensing and GIS, and the King Mongkut Institute of Technology Ladkrabang (KMITL) provides weather information for each country in Asia and the Pacific. Additionally, drones are used for crop monitoring and delivering pesticides and fertilisers. However, this is concentrated in central Thailand, and rural poverty did not decrease from 2014 to 2018 (Ahmed et al. 2023). The latest census has been delayed due to COVID-19, so it is not clear if the farmers in the Northeast are benefiting from the technology introduced to reduce poverty.

Discussion

Biosecurity for rice blast mitigation in IPR countries and PSIDS

Biosecurity surveillance is essential to managing rice blast across the pre-border/border/post-border continuum. A recent example demonstrates that a strong understanding and management of inoculum reservoirs in Australia helps protect crops and minimise disease outbreaks (Pak et al. 2021) by focusing on early detection and rapid response. In 2024, there was a detection of *P. oryzae* in a rain-fed summer rice crop in northern NSW where winter wheat is grown, but outside of the rice biosecurity zone around the primary rice growing area (Department of Primary Industries Biosecurity NSW 2024). This infection was potentially transported via a recent cyclone, and the response was immediate upon reports to the Department of Primary Industries, NSW, resulting in an alert to farmers, the destruction of the crops in infected fields with water containment on property to reduce spread, and future crops in this area to only use resistant rice varieties (ABC News 2024). The Department of Primary Industries Biosecurity (NSW) worked with farmers in the northern region to manage biosecurity, while increasing surveillance and awareness in the southern regions Rice Biosecurity Zone (The Farmer 2024, Department of Primary Industries Biosecurity NSW 2025). Rapid, comprehensive responses to detection of pests or pathogens results in avoiding the introduction, spread, and impact of pests and diseases.

The efficacy of national biosecurity measures will be greater if they are simultaneously implemented by multiple countries (Latombe et al. 2020). For example, Australia, and its near neighbour New Zealand, are recognised for their commitment to biosecurity measures to protect their nations (Dodd et al. 2020, Stone 2021) and are prominent investors in the Pacific region. A bilateral arrangement, the Australia New Zealand Biosecurity Cooperation (ANZBC), identifies differences in biosecurity risk management procedures between the countries and develops conformity in their approaches. Australia operates one of the most compre-

hensive biosecurity systems in the world (Dodd et al. 2020) using a multi-layered system, involving complementary measures applied along the biosecurity continuum (Fraser 2016) using a risk-based approach to protecting its food security from increasing pest and disease incursions due to trade, and greater movement of serious pests and diseases occurring on a global scale (Dodd et al. 2020). The Ministry for Primary Industries Biosecurity New Zealand, also known for its prioritisation of early detection, has a strong emphasis on community participation and partnerships (Stone 2021). Some of these biosecurity approaches and systems might be used in IPR countries.

For an active biosecurity system, there are many activities to undertake, for example, farmers and extension workers must be trained to recognise the pathogen in their areas and promptly report its presence. There is potential for citizen science projects to aid detection and surveillance (Jactel et al. 2020), which also increases education and information dissemination about the disease. However, these projects require confirmation of records. The use of the latest accessible technology, such as mobile phones with AI-powered apps (Selvaraj et al. 2019), can be beneficial depending on the socio-economic status of the region. Agencies employing remote sensing and other applications can also inform on-ground actions to be taken; for example, in India, an Optimized Deep Neural Network (Jaya Algorithm) achieved 98.9% accuracy in detecting rice blast-affected crops (Ramesh and Vydeki 2020). Although rice blast is endemic throughout most IPR countries, strict measures must be employed once detected to contain and limit its spread.

Pre-border biosecurity activities include fulfilling obligations to the International Plant Protection Convention (IPPC). This includes capacity building in neighbouring countries, gathering pest intelligence, undertaking risk analyses and import approvals, engaging in export market access negotiations, and undertaking offshore assessment, audit, and verification of import items. In the IPR, several international agreements govern plant biosecurity. Each signatory to the IPPC has its own National Plant Protection Organisation, which implements the International Standards for Phytosanitary Measures, safeguarding agriculture and the environment from the negative impacts of pests and supporting a national system to prevent introduction. Trade networks are vulnerable to rice blast spread should the grain be infected; hence, adherence to strict trade regulations by the World Trade Organisation and IPPC phytosanitary measures is necessary for food security stability (Thuong 2018).

Border biosecurity is another stability mechanism. It requires a risk management system, inspection and monitoring, enforcement and compliance, and education and awareness. One of the significant biosecurity implementation problems in the IPR is porous borders. Pest introduction is more likely to occur without strict biosecurity border inspections or surveillance. Borders may be complex to manage due to the unrestricted movement of people and goods, with informal border crossings throughout the IPR (Ullah and Kumpoh 2018, Faye 2021). Border inspections and surveillance are crucial to prevent the introduction of pests and diseases, as biosecurity risks are growing and increasing in complexity. Biosecurity risk management in IPR countries and PSIDS remains a considerable challenge due to the different approaches to biosecurity legislation, protocols, and standards between countries (Castriciones and Vijayan 2020). A unified approach encompassing a community of practice within the region would be beneficial for ensuring stable food security.

Post-border biosecurity further reinforces food security stability. It requires monitoring and surveillance, national coordination and response to pest incursions, domestic quarantine, a capacity for emergency preparedness (emergency response plans), developing capacity to prepare, detect and respond to pests and diseases (training), ongoing practice, simulations, education and awareness, and information dissemination on effective pest management protocols. Introducing incentives to encourage early detection and notification by growers and others of suspicious plant pests has been a successful strategy.

Individual IPR countries have made progress in implementing biosecurity measures. For example, Cambodia drafted biosecurity legislation in 2022 to strengthen its market access (Phanet 2022). Currently, there are calls for Malaysia to undertake a comprehensive evaluation of their Biosecurity Law to support the established regulatory frameworks for the mitigation of biosecurity risks and ensure protocols/interventions are implemented (Shafie and Osman 2024). However, Cambodia's 2021 Global Health Security Index scores indicated no legislation or regulations related to biosecurity to address physical containment and operation practices and no agency designated to lead implementation or national training curriculum for biosecurity (GHS Index 2021). The IPR countries are at different stages of preparedness, requiring all trading partners to focus on pre-border biosecurity. Given the unifying importance of stability in the food security pillars, a strategic approach to regional biosecurity for rice blast is proposed, with measures across the biosecurity continuum (Fig. 5).

While integrating risk mitigation measures to withstand future losses, it is important to empower farmers, particularly women who do most of the work in the field, with professional training in phytosanitary measures so that they can implement effective biosecurity practices locally (OECD and ASEAN 2021), e.g., seed sharing. At the community level, providing the capacity for individuals and groups (particularly women and the disadvantaged) to offer opinions and make decisions about agriculture development projects and food system governance can result in better food security outcomes (Burchi and De Muro 2016). Therefore, all humanitarian efforts should be sensitive to the needs of vulnerable communities such as women, children, the elderly, people with disabilities, ethnic and religious

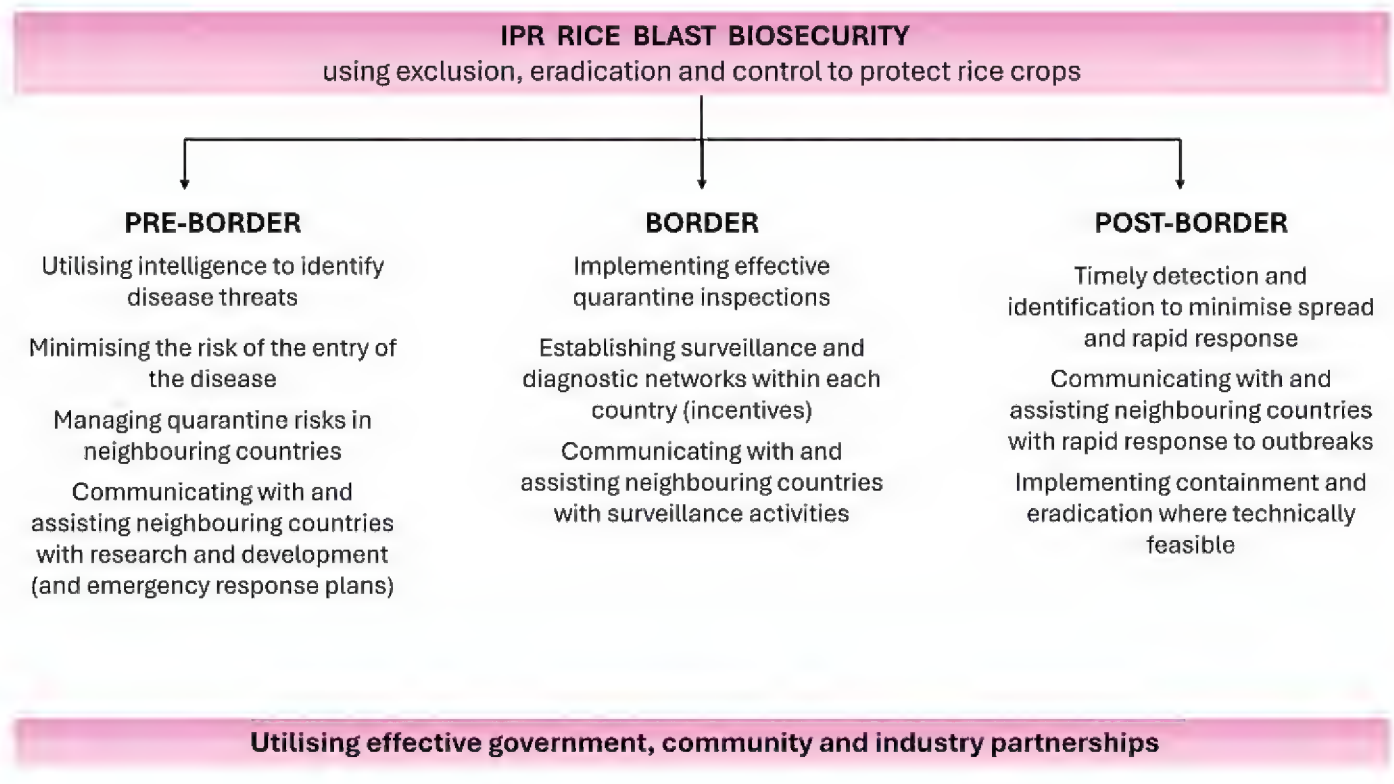
IPR RICE BLAST BIOSECURITY
using exclusion, eradication and control to protect rice crops
PRE-BORDER
Utilising intelligence to identify disease threats
Minimising the risk of the entry of the disease
Managing quarantine risks in neighbouring countries
Communicating with and assisting neighbouring countries with research and development (and emergency response plans)
BORDER
Implementing effective quarantine inspections
Establishing surveillance and diagnostic networks within each country (incentives)
Communicating with and assisting neighbouring countries with surveillance activities
POST-BORDER
Timely detection and identification to minimise spread and rapid response
Communicating with and assisting neighbouring countries with rapid response to outbreaks
Implementing containment and eradication where technically feasible
Utilising effective government, community and industry partnerships

Figure 5. A proposed approach to rice blast biosecurity in the Indo-Pacific Region. Adapted from Department of Primary Industries Biosecurity Victoria (2005).

minorities, and refugees. Agricultural policies should factor in women's involvement in all rice production operations, including seeding and pest management (Kawarazuka et al. 2020). The causes of vulnerability in rice production are best addressed by biosecurity measures which focus on understanding and respecting cultural sensitivity.

Investing in data gathering and reporting for plant pests and diseases allows stakeholders to make prompt strategic decisions. Thorburn (2015) had indicated the need for more publicly available government statistical and technical data in the IPR and PSIDS. However, Indonesia, for example, perceives rice production statistics, information on rice pest infestations, and crop losses as politically sensitive (Thorburn 2015). In 2015, the Grow Asia Exchange, was established by the World Economic Forum, in collaboration with the Association of Southeast Asian Nations (ASEAN). Grow Asia Exchange unites governments, non-governmental organisations, the private sector, and other stakeholders to organise, facilitate, and promote "inclusive, resilient and sustainable food systems" (https://www.growasia.org). A data hub, the Global Burden of Crop Loss (established in 2019 and led by CABI) is an international, intergovernmental, not-for-profit organisation that "collates, curates and analyses data from open data sources" (https://www.cabi.org/global-burden-crop-loss). These two organisations provide valuable data sources for information collation and research initiatives (McLaughlin 2022). Similarly, the aim of the One CGIAR Plant Health Initiative (Consortium of International Agricultural Research Centers) is the prevention and management of major disease and pest outbreaks by developing and disseminating inclusive innovations – this can be achieved by developing national, regional, and global networks (McLaughlin 2022). Across the IPR, standardised monitoring and reporting of all outbreaks (Latombe et al. 2017) and detecting new variants will support risk analyses of localised outbreaks and the potential for natural long distance dispersal (Faulkner et al. 2020). Resourced and well-coordinated regional networks are important as platforms for monitoring and early warning systems for disease notification, e.g., the FAO and the Asia Pacific Plant Protection Commission. Many countries consider this an integral aspect of their armed forces' mission. The military is often praised for its frontline responses to food aid and disasters by utilising its unique capabilities and rapid deployment in large-scale operations (Tinti 2024). Hence, the role of these agencies in biosecurity to ensure food security needs to be further explored.

Recommendations

How to improve biosecurity for rice blast in the IPR (and PSIDS)

The security and prosperity of the IPR (and PSIDS) are linked to the security and prosperity of its neighbours and vice versa (Moore 2023). With much to offer via trade and investment, and the need to manage rice blast in their crops, Australia may assist in maximising the region's prosperity (Moore 2023). The human security framework, intersecting with food security and national security, focuses on transitioning from humanitarian response to sustainable development and preventing crises (UN Trust Fund for Human Security 2018). Implementing biosecurity measures, as outlined by various international agreements and frameworks, is crucial in managing plant pests effectively while safeguarding agricultural production and the

environment. Australia is recognised for its world-leading biosecurity system with robust standards compliance and commitment to ongoing research and improvement (Commonwealth Scientific and Industrial Research Organisation 2025). For example, the Australian Department of Agriculture, Fisheries and Forestry (DAFF) has strong compliance and enforcement tools to control, reduce, and monitor biosecurity threats (Durant and Faunce 2018). There is an opportunity to build strong legal and policy frameworks (Moore 2023) by utilising the established DAFF protocols for administering the local biosecurity legislation in the IPR countries, and implementing local procedures to supplement the IPPC standards.

Many countries' military agencies have provided strategic and resource planning in response to increased extreme weather events (Jayaram and Brisbois 2021). While there are different approaches used by the agencies involved, it will be helpful to develop an overarching One Biosecurity convention (Hulme 2021, Hulme et al. 2023) for the IPR by focussing on a regional biosecurity approach that increases stability in the food security pillars, and utilising interdisciplinary communication (Hulme et al. 2020) across the biosecurity continuum. These integrated risk reduction strategies can also help overcome future food shocks (Tinti 2024) and benefit other countries that may import rice. Defence involvement with biosecurity provides great strategic value in researching and responding to the evolving biosecurity landscape and its potential implications for national and regional security.

Biosecurity requires strong partnerships to support effective collaborations between stakeholders at all levels (Miley 2020). For example, the Asia and Pacific Plant Protection Commission (https://www.apppc.org/) is invaluable because it provides a platform for member countries to exchange information on plant protection and quarantine, outbreaks, surveillance, and pest and pesticide management. The Australian Defence Force (ADF) has strong ties with security in Malaysia, the Philippines, Thailand, Timor Leste, and Indonesia (Moore 2023). The IPR countries and PSIDS are of strategic importance to Australia's national security due to their proximity with shared marine environments, trade connectivity, financial integration, and close multicultural ties (Australian Government Department of Trade and Foreign Affairs 2017, Department of Defence 2020, Heiduk and Wacker 2020). The ADF, and other Australian Departments, could assist with strengthening and developing new systems such as pre-border activities, identifying threats through intelligence gathering and pathway modelling. They may help in surveillance and provide resources and infrastructure to be repurposed for biosecurity initiatives, such as mobile laboratories and diagnostic capacity for pathogen analysis, or logistical support for emergency responses. At the borders, the ADF could guide intervention levels through risk-based surveillance. When required, the provision of personnel can increase the number of checkpoints. Post-border preparedness can be supported via surveillance, outbreak and control modelling, and assistance with developing effective biosecurity risk management. During rice blast outbreaks, the ADF could support on-ground operations, such as emergency response assistance, surveillance and delimiting surveys, the decontamination of vehicles, and quarantine and containment to prevent disease spread.

By considering the vulnerabilities, threats and gaps in plant and food biosecurity, Australia could boost regional stability by extending trusted partnerships and using a humanistic approach to mitigate plant pests and diseases and reinforce biosecurity across many nations. This will reduce the impact of plant pests and diseases on food security in the IPR and PSIDS.

Conclusion

With only a small percentage of rice crops traded internationally, self-sufficiency is crucial to ensure national food security, where rice is the staple crop. Rice blast poses a significant threat to food production in the IPR countries, affecting all dimensions of food security, availability, access, and utilisation, undermining stability. Growing globalisation and trade increase the risk of entry, establishment, and spread of rice blast and other plant pests and will continue unless efforts are directed toward a unified approach to biosecurity.

Generally, food insecurity in the IPR countries and PSIDS is more about access than availability issues as the region continues to produce rice fairly consistently despite the challenges. However, the effects of climate change on increasing rice blast disease outbreaks can negatively impact access, utilisation, and stability, causing huge disparities between the countries in the region. The stability of the rice supply is further hampered by conflicts, droughts during El Niño, and trade restrictions by major rice producers like India, all of which cause a significant threat to the population in the region (FAO 2024, Valera et al. 2024). Poor social, economic, and political policies and residual effects of the COVID-19 pandemic are still being felt in the region, with increasing food insecurity experienced in some IPR and PSIDS countries.

The important principles that should be the foundation of plant biosecurity policies and operations include the concept of the plant biosecurity continuum, utilising risk management, and complying with international standards. To be effective, the biosecurity system needs all stakeholders to work together across the continuum (pre-border, border and post-border activities). A unified approach to communicating with, and assisting, neighbouring countries with all aspects of the biosecurity continuum could provide the best outcomes for food security.

Further suggestions to reduce food insecurity include introducing incentives to encourage early detection and reporting of potential plant pests, identifying more cost-effective ways to manage rice blast, providing more education opportunities for farmers via trained technical officers running awareness courses and providing timely communication with farmers, and encouraging an increased level of industry funding contribution, responsibility and involvement in the regions plant biosecurity. Improving plant biosecurity will reduce rice farmers' costs and the number of outbreaks which are pushing the lower socio-economic rural farmers below the poverty line. Education and training can have a flow-on effect in reducing human and environmental health risks from using pesticides. Accurate weather forecasts for rice farmers can allow them to plan for the probability of disease. Early disease detection can help extension officers and farmers manage and reduce crop losses by prompt intervention. Disease forecasting and monitoring modules provide early warning systems to help plan planting schedules and chemical control measures. Remote sensing, imaging technologies, and molecular diagnostics offer powerful tools for early and precise disease detection. These can be applied to all crops in the region, irrespective of the pest or disease of interest, and indeed can be used to detect new incursions.

Food security in the IPR can be improved by moving from responding to crises, to preventing disease outbreaks by progressing the development of frameworks based on Australian and New Zealand protocols to supplement the IPPC standards. Strategic planning and building resource capacity to increase stability may be provided by the ADF which are readily deployable, and have strong ties in

many IPR countries. The ADF can assist with pre-border, border and post-border activities based on surveillance and the provision of extra personnel when required, as many tasks that they already carry out (e.g., risk analysis/mitigation, detection/surveillance/monitoring, diagnostics, emergency responses, distribution of food aid and community engagement) can be easily modified to suit disease outbreaks. This could extend beyond rice blast to other diseases.

Supply chain resilience is also required to support the region's geopolitical stance and the economic benefits of trade. Having an insight into the future behaviour of the regional rice market is extremely important to help governments and stakeholders develop collaborative strategies to assist all countries in reducing food insecurity due to disease outbreaks. With adequate infrastructure, effective policies and research investment, international cooperation is crucial for improving the IPR and PSIDS biosecurity and increasing food security. The aim is to form sustainable and resilient food systems that can meet the nutritional needs of a growing population while safeguarding environmental resources (Asma et al. 2023).

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Use of AI

The AI-powered tool Grammarly was used to edit the final draft, but not to write. The final draft was also confirmed to have 0% AI using Turnitin.

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Author contributions

KH investigation and data collection, data analysis and interpretation, writing – review & editing. BK sample design and methodology, writing – original draft. RS research conceptualization, writing – review. CH acquired funding, writing – review. KLB research conceptualization, and writing – review & editing.

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Data availability

All of the data that support the findings of this study are available in the main text.

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